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CHEMICAL & ENGINEERING

NEWS

Plastics Recycling

Industry responds to solid waste crisis

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News of the Week

■ **Savannah River plant's nuclear reactors are still being plagued by mishaps, delaying plans to restart them later this year.** **Page 4**

■ **AAAS's new executive director will be chemist Richard S. Nicholson, who is currently head of the mathematics and physical sciences directorate at NSF.** **Page 5**

■ **The current in a new type of superconducting copper oxide prepared by Japanese researchers is carried by electrons, rather than electron vacancies, as in all previous copper oxides.** **Page 5**

■ **Australian high school student, winner of science award for process to coat steel with diamond film, visits Penn State University during trip to U.S., part of his award prize.** **Page 5**

■ **Chemical company earnings' strong growth pattern carried into last year's fourth quarter.** **Page 6**

Cover: Photo by C&EN's Ann M. Thayer

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LETTERS

CHEMICAL SAFETY

Explosive pyridine derivative

SIR: Recently an explosion occurred in our laboratories during the attempted synthesis of 3-methyl-4-nitropyridine-1-oxide according to W. C. J. Ross [*J. Chem. Soc., C, Org.*, **1966**(20), 1816]. 3-Methyl-pyridine was converted into the corresponding 1-oxide using hydrogen peroxide and glacial acetic acid. After evaporation under reduced pressure, subsequent addition of sulfuric and nitric acid and slight heating as described, a sudden vigorous reaction occurred followed by an explosion after a few seconds.

Fortunately, thanks to the alertness of the experimenter and his colleagues, no personal injuries occurred. As the explosion is most probably caused by the presence of remaining peracetic acid from the nitrogen-oxidation step in the subsequent nitration step, we advise not to follow the published procedure for the synthesis of 3-methyl-4-nitropyridine-1-oxide.

A. v.d. Kuilen
J. A. J. den Hartog
Duphar B.V., Weesp, Holland

Alcohols in fuels

SIR: W. C. Lowrey's letter, entitled "Octane Enhancers" (C&EN, Dec. 5, 1988, page 3), included several statements that require a response. Lowrey implies that application of the federal blender tax credit to ethyl *tert*-butyl ether (ETBE) would be "unwise and unfair." Quite the contrary in the estimation of lawmakers who enacted the blender tax credit in 1980. Specific blend proportions of waivered fuels now in commerce were, in several cases, undetermined at that time. However, the use of alcohols in these fuels was clearly anticipated. The 1980 blender tax credit was simply a means of stimulating the future use of such fuel components. The application of the blender tax credit to ETBE is precisely the type of application anticipated by lawmakers in 1980. Recent letters to that effect have been sent to the Treasury Department by more than 70 members of the Senate. The applicability of the blender tax credit to ETBE is merely a clarification of current law, not enactment of new legislation.

Lowrey also invokes the very old and tired "food versus fuel" myth regarding corn used for ethanol. His citation of this fallacious argument indicates a lack of understanding about the international food and feed situation. As one example, less than 10% of the corn grown in the U.S. is used directly for human food. The majority is used for livestock feed, primarily as a protein source. Ethanol is derived only from the starch in corn. The protein is extracted and used in a variety of food and feed applications. The use of corn as a feedstock for ethanol has not [competed], and in the foreseeable future will not compete, with human requirements.

Todd C. Sneller
Administrator, Nebraska Gasohol Committee

Energy efficiency

SIR: In reference to a letter from Rep. Claudine Schneider (C&EN, Nov. 14, 1988, page 5), I would like to raise some questions concerning energy efficiency.

The so-called empirical results over the past 10 or more years of a 30% drop in energy required to produce a dollar of gross national product and a 40% drop in CO_2 emissions may be at least partially explained in the following. During the past 10 or 20 years, heavy industry (such as steel production) has been on the decline in the U.S. Such heavy industry tends to use more energy and produce more CO_2 than the more service-oriented economy we now have. Also, the lower value of the dollar now than 10 years ago would be expected to yield a lower energy per dollar figure.

The above-quoted figures for the U.S. as presented in the first paragraph of Schneider's letter were perhaps inadvertantly applied to the whole world in the second paragraph. Is this a correct application of these figures?

The important question therefore is: Have we really achieved this improved efficiency nationally or worldwide, or is this but another instance of conveniently interpreted or manipulated data? My opinion is that we have not achieved nearly so much as quoted in Schneider's letter. We need to do much more!

Joseph A. Counsil
Assistant Research Engineer
University of Missouri, Rolla

Fluoridation of water

SIR: In his defense of water fluoridation, Surgeon General C. Everett Koop (C&EN, Nov. 28, 1988, page 2) claims that "those who have had lifelong access to fluoridated drinking water experience less dental decay, on average, than those who have not had such access."

This is not true in Australia or New Zealand. For instance, primary schoolchildren in the Australian state of

Solid Waste Concerns Spur Plastic Recycling Efforts

With plastics taking up 30% of volume of municipal solid waste and costs of landfilling and incineration rising rapidly, waste reduction efforts focus on development of plastics recycling technology

Ann M. Thayer,
C&EN Northeast News Bureau

The management of solid waste is reaching a crisis in the U.S. and worldwide. This is illustrated by wandering garbage barges with no permission to land and by wastes washing up on beaches.

Every year the U.S. generates about 320 billion lb of what is called municipal solid waste, or postconsumer waste. About 85% of this trash is currently disposed of in landfills. Yet as the amount of solid waste increases—and the Environmental Protection Agency estimates that it will reach 380 billion lb by 2000—a third of the landfills are expected to close in the next five years. Many people are concerned that efforts to deal with the growing quantity of garbage are not moving fast enough.

C&EN staff photo

Baled plastic bottles from local communities await recycling

Plastics make up only about 7% of solid wastes, according to figures prepared by Franklin Associates for EPA, but plastics and paper are the fastest-growing segments of such wastes. In 1987, the plastics industry produced a total of 55 billion lb of plastics, and the public discarded about 22 billion lb of that. By 2000, plastics production may reach 75 billion lb, and the public is expected to throw away about 38 billion lb of that, accounting for 10% of solid municipal wastes that year. Although not a significant proportion by weight, plastics have been targeted as a waste problem since, by volume, they are a very visible 30% of municipal solid waste.

Rapidly rising costs of landfilling, as high or higher than $100 per ton in some parts of the U.S., and of alternative waste treatment methods, such as incineration, are making it prohibitively expensive to deal with large amounts of waste. When coupled with the desire to conserve resources and have an environmentally acceptable means of reducing solid waste, recycling is often considered as an alternative. Recycling, although not inexpensive itself, can be less costly than other disposal methods because there is both a return on the reused materials and an offset of landfill charges. Of the more than 300 billion lb of solid waste produced, only about 10% is recycled annually. Aluminum and paper are the materials recycled most, with about 30% of the aluminum and 20% of the paper reprocessed. Only 1% of the plastics is recovered.

The apparent lack of movement in plastics recycling has helped to make plastics a scapegoat in the battle

C&EN staff photo

Clean, ground recycled polyethylene milk bottle chips fall from pilot plant equipment into bin

on solid waste. In the past decade, plastics have become increasingly prevalent because of their light weight, versatility in a range of applications, and convenience. But many plastic consumer items have short life spans and quickly make their way into the waste stream. More than half of the discarded plastics are found in the form of packaging, an area frequently targeted for recycling. Packaging, about one third by weight of consumer waste, consists primarily of paper (48%), glass (27%), and plastics (11%).

Much of the public believes that plastics cannot be recycled or safely incinerated and, because they do not decompose, that they should be removed entirely from the waste stream. One can argue as to whether plastics are in fact a major cause of the solid waste crisis, but the answer is almost irrelevant since plastics are generally perceived to be a significant problem.

The result has been the rapid introduction of a tremendous amount of local, state, and federal legislation that attempts to deal, one way or another, with the problems of solid waste. Much of the legislation has been aimed directly at plastics. On the federal level, former President Reagan signed the Plastic Pollution Control Act on Oct. 28, 1988, requiring that all six-pack ring carriers be made of biodegradable materials. The act will go into effect unless, in the next two years, EPA determines that it is either not feasible or that the by-products of the biodegradable materials are not environmentally safe. Efforts to deal with solid waste issues are also expected to continue with a reauthorization of the Resource Conservation & Recovery Act, which at this time promotes recycling only through government procurement guidelines.

The most comprehensive federal legislation proposed to date was reintroduced this month by Rep. George J. Hochbrueckner (D.-N.Y.). The bill, H.R. 500, entitled the "Recyclable Materials Science & Technology Development Act," has been described as the first measure introduced to authorize a comprehensive consumer product recycling program on a national level.

The bill stipulates that after a four-year joint review by EPA and the Commerce Department, all consumer items deemed recyclable would be identified and listed. Items determined to be recyclable must then be recycled, and all remaining items must be made biodegradable. After an additional year, the sale of certain nonrecyclable or nonbiodegradable consumer goods would be prohibited. The bill would establish an Office of Recycling Research & Information to distribute information and funds for research. Commerce would be directed to look into ensuring technology development, expanding the end-use markets for recycled materials, and encouraging the development of biodegradable products.

On the state level, the interplay of plastics and legislation began in 1978 with the introduction of the polyethylene terephthalate (PET) beverage bottle. In a relatively short time, nine states introduced "bottle bills," or deposit laws on the return of plastic bottles. In these states, the deposit laws account for collection of an estimated 80 to 95% of the PET bottles sold. At present, at least 30 states are looking into some sort of waste management legislation involving plastics.

The existing or proposed legislation runs the gamut of possible approaches, from the relatively benign sponsoring of feasibility studies for recycling to outright bans on the use of plastics. Other approaches include limited bans on certain items, such as polystyrene food containers, taxes on bottles or other containers, deposit laws, enforced usage of biodegradable materials, and restrictions on government procurement of recyclable or degradable items. In addition, voluntary or mandatory recycling programs are starting in many states. Susan Vadney of the Society of the Plastics Industry (SPI) Council on Solid Waste Solutions indicates that at least nine states have recycling programs and six more are likely to follow.

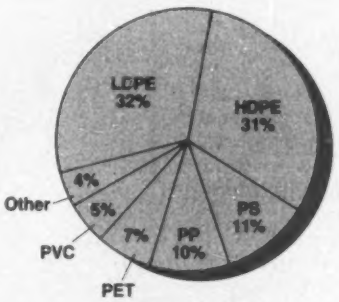
A few states such as Rhode Island, New Jersey, and California have become models for recycling programs, with Rhode Island and New Jersey having mandatory programs. In both states, several communities have had successful pilot programs for recycling that have included plastics. In October 1987, California enacted a mandatory beverage container redemption law (AB2020) with the condition that plastics manufacturers guarantee end-use markets for recycled plastics.

Massachusetts, in a joint study with Rhode Island, has recently released a Plastics Recycling Action Plan. The plan includes plastics as a significant part of a comprehensive recycling program aimed at reducing municipal waste levels 25%. The plan promotes pilot programs and further R&D into all aspects of recycling. Added incentives to recycling sometimes take the form of potential legislated penalties, such as taxes or deposits, that would be imposed if recycling goals, or those for certain materials, are not met. These incentives are often directed at bringing the recycling of plastics up to a level comparable to aluminum cans and glass bottles. Some states, like New Jersey, are also offering business loans, R&D funds, tax credits on equipment purchases, and market stimulation as incentives.

Five resins are in common use in consumer packaging

Thermoplastics, which account for 87% of plastics sold, are the most recyclable form of plastics because they can be remelted and reprocessed usually with only minor changes in their properties. Five resins are commonly used in consumer packaging applications.

Polyethylene is the most widely used resin. High-density polyethylene (HDPE) is used for rigid containers such as dairy and water jugs, household product containers, and motor oil bottles. Low-density polyethylene (LDPE) is often used in films and bags.



U.S. total 1987 production of packaging resins = 12.7 million lb

Source: Center for Plastics Recycling Research

Polyethylene terephthalate (PET) is used extensively in rigid containers, particularly beverage bottles for carbonated beverages.

Polystyrene (PS) is best known as a foam in the form of cups, trays, and food containers. In its rigid form it is used in cutlery.

Polyvinyl chloride (PVC) is a tough plastic often used in construction and plumbing. It is also used in some food, shampoo, oil, and household product containers.

Polypropylene (PP) is used in a variety of areas, from snack food packaging to battery cases to disposable diaper linings. It is frequently interchanged for polyethylene or polystyrene.

On a local level, some of the legislation already passed has made people take notice, since its approach has been more drastic. Suffolk County, New York, was one of the first counties to ban plastic food packaging—the apparent target being fast-food packages made of polystyrene. Similarly, Berkeley, Calif., banned all polystyrene packages made with chlorofluorocarbon (CFC) blowing agents. The Berkeley law requires that all fast-food restaurant containers be biodegradable by 1990.

Although the reaction by government has been fairly rapid and directed, the issue of plastics in the waste stream is complex. The number of legislative moves to ban plastics or replace them with biodegradable materials is increasing. Critics say that these approaches are based on misinformation and misconceptions, and are only a politically expedient response to the public's desire for solutions that appear to be environmentally safe. But biodegradable materials and plastics may not be the answer.

"There are still a lot of unanswered questions about biodegradable plastics," says Mary Sheil, deputy director of New Jersey's Division of Solid Waste Management and one of the drafters of that state's mandatory recycling law. Among these questions are concerns about the degradation products and how they will affect the environment. In addition, the introduction of degradable materials is often considered at cross purposes to recycling, because the degradable items can become contaminants of the more stable recyclable materials. One of the most startling facts that is coming to light is that even materials that are expected to decompose, such as paper and foodstuffs, are not breaking down in landfills. Therefore, producing more biodegradable materials would not necessarily ease the burden on landfills.

Public perception and the resulting trends in legislation have led manufacturers of plastics and plastic products to realize that they either have to act and get involved with the issue or be prepared to shoulder much of the blame for the solid waste crisis and face tremendous restrictions on their industry. The companies' initial responses included the formation of both internal divisions and cooperative industry associations to approach the issues of plastics recycling and solid waste management.

"Fortunately, we had some visionary people," says Wayne E. Pearson, executive director of the Plastics Recycling Foundation (PRF), an independent, nonprofit organization started through the Society of the Plastics Industry in 1985 by 20 members of the plastics and allied industries. "This group recognized, before it was as apparent to most of us, that there was a solid waste crisis, that recycling was important and that [group members] needed to know more about it." The foundation now has 45 member companies, ranging from resin producers to container manufacturers to users of the containers, who are concerned about

C&EN staff photos

Morrow (left): very ambitious objective. Pearson: ban on plastics is not the answer

the attitudes driving today's legislation and would like to see it take a new direction. "The legislation is coming from a quick fix," says Pearson. "And it's too early to make simplifying decisions, unless you know the impact on society and the environment.

"But," he says, "what we can't let it do is cause us to panic. We are trying to get a message out there about recycling, but get it out there in a calm and rational way. We want to get to various legislators and let them know that when they have the facts, they will see that banning plastics is not the answer."

But how and where does a group like this get its facts? In 1985, PRF made its primary objective the establishment and support of the Center for Plastics Recycling Research (CPRR) at Rutgers University. Funds totaling nearly $2.3 million in 1988–89 to support research come from PRF, Rutgers University, and other organizations such as SPI, the National Science Foundation, the New Jersey Commission on Science & Technology (which has established CPRR as one of its Advanced Technology Centers), and several state governments and universities. In the near future, Rep. Jim Courter (R.-N.J.) is expected to reintroduce a proposal to fund the center as the National Center for Plastics Recycling, the hub of a national effort with other universities.

Starting up a research program in recycling is not an unlikely thing for plastics manufacturers to do, Pearson points out. "One of the things I don't think the public at all understands is that the plastics industry recycles every plastic, every thermoplastic, every day." He explains that the reprocessing of in-house scrap from the manufacture of plastic products has been a common practice for as long as the industry has existed. Thus, much of the technology for reusing plastics already exists. But, he notes, the use of in-house scrap is relatively straightforward, since collecting and sorting the materials is not necessary. So the question CPRR was given regarding plastics recycling was, Pearson says: "How do you gather it back from 240 million Americans and do something with it that makes any sense?"

Under a charter to advance R&D in all aspects of plastics recycling and reuse, the job has been given to Darrell R. Morrow, director of CPRR, and his staff. The center operates with three divisions—research, process development, and information services—that work on covering the scientific, technological, economic, environmental, and practical sides of recycling plastics. This includes defining and developing the necessary infrastructure to recycle plastics. This framework consists of four areas: collection, sorting, reclamation, and reuse. Unlike other materials such as paper, metal, and glass, which have been recycled for 40 years or more, the infrastructure for plastics recycling is not yet in place.

The center initially concentrated on reclamation and reuse and developed a technology for the reclamation of postconsumer waste plastics. After only two years, CPRR published nearly 25 reports based on its research and held conferences to provide for transferring the technology. "We want to disseminate the information as widely and in as timely a fashion as we can to help develop the infrastructure that will cause plastics to be included in the recycling stream," says Morrow.

C&EN staff photo

Dittman sits on plastic bench made at CPRR plant

In its first two years, CPRR also constructed and began operating what is potentially a commercial-scale pilot plant facility. "To be able to reduce the applied research to practice in a timely manner," says Morrow, "we realized that we had to have a process development and demonstration facility that was significantly larger than you would ordinarily expect to find at a university, or even in industry." He adds that this has allowed them to move along faster toward a commercially viable design.

Through this focused effort, CPRR has produced a technology transfer manual that describes in detail the setup and operation of a plastics recycling plant. The hope of CPRR is that making the technology available will foster the commercialization of plastics recycling. There are currently 14 licensees of the CPRR process worldwide; two of them are looking into building plants in the near future.

The process developed at CPRR is said to be similar in its layout to those used in private industry. Most plastic reclamation systems are designed to work with rigid containers, such as PET beverage bottles, and HDPE milk or household product containers, because they are currently the easiest postconsumer items to collect and sort. PET beverage bottles are actually not one, but several materials: a PET body (clear or green), a pigmented high-density polyethylene (HDPE) base cup, aluminum cap, label, and adhesives. To separate these components, either a dry or wet separation method based on one or more of the different physical properties of the materials can be used.

Frank W. Dittman, project manager at the CPRR

plant, describes its operation after the containers have been collected and delivered to the plant. The bottles are sorted by hand to separate out the more valuable resins. "We are looking at mechanical sorting based on optical and electrical principles," says Dittman, "but whether that's going to beat hand sorting at cost, I don't know. You can sort by hand pretty quickly." After sorting, the bottles are shredded and ground into chips for processing. The chips are then air classified, which, Dittman says, means that the lighter weight paper and other contaminants are separated in an air cyclone from the heavier plastic chips.

To remove the labels still attached to the chips, a cost-effective and efficient means of removing a waterproof adhesive had to be devised. After finally finding a detergent wash that would work, he explains, it had to be optimized with respect to temperature, washing time, concentration of detergent, power of mixing, and, of course, concentration of chips.

In the case of the multicomponent PET beverage bottles, once the labels are removed, the lighter HDPE fraction is separated from the heavier PET and aluminum pieces in a hydrocyclone system. It is at this stage that other reclamation methods often differ, using a separation step based on flotation methods; Dittman suggests that the hydrocyclone system will be an improvement over the flotation methods. The HDPE chips are then dried and collected.

The PET and aluminum chips require further drying so that they can be electrostatically separated. This is the most expensive part of the entire process. "The aluminum cap is only 1% by weight of the bottle," explains Dittman, "but the equipment to remove it represents about 30% of the investment in the plant. It's out of balance, and we are trying to remove the aluminum more cheaply." The process—which at the CPRR plant can handle about 600 lb per hour, or a potential capacity of about 5 million lb per year—generates clean, well-separated (99.9%) granulated plastic chips that can be sold to a manufacturer who uses the resins.

The chips sell for about 25 to 35 cents per lb for PET (with less than 100 ppm of aluminum), and 17 to 25 cents per lb for HDPE. In comparison, virgin PET costs about 50 to 60 cents per lb, and HDPE resins about 40 cents per lb. The center combines these and other factors in evaluating the financial aspects of operating a plant. "In our engineering manual we analyzed the economics and showed that a profitable plant should be able to process 20 million lb a year or more," says Dittman. He notes that the investment for a plant of that size would be about $2.5 million and it would pay for itself in three to five years.

Other available reclamation technologies for rigid HDPE plastics are made by Transplastek of Canada and A.K.W. of West Germany and are similar in design to the CPRR process with granulating, washing, and separation steps. Transplastek uses a proprietary flotation tank method to separate plastics by density, whereas the A.K.W. method is based on the hydrocycloning technology.

Much of the resin reclamation and reprocessing technology comes from overseas, as the Europeans and Japanese have been involved in recycling for a longer period of time. There are other reclamation processes for different resins, which have been developed by or licensed to private companies, but because these are usually proprietary the details of their operations are not known.

Morrow makes a point of calling the system designed at CPRR a "resin recovery system," to stress the fact that it will work on about five different resins. Currently PET and HDPE can be processed together and are easily separated because of their different densities. The center hopes to add polystyrene and polyvinyl chloride to the mixed plastics stream they process. But, with the present technology, PET and PVC cannot be run together since they have similar densities.

"We have a very ambitious objective," says Morrow. "What we have challenged ourselves to is to make our resin recovery system a universal reclamation facility." Ideally, he explains, one would like to be able to feed in mixed, even granulated, plastics and have pure, generic resins come out the other end. This would remove the need for hand sorting and, for example, the separate processing of pigmented and unpigmented HDPE containers. Morrow notes that economics are driving this stage of the reclamation process: Colored HDPE is less valuable than uncolored HDPE, which has greater flexibility in end uses.

The value of recycled materials is present only if there are available markets, and plastics have become the second most valuable recyclable material after aluminum. The greatest return on recycled plastics is gained when the resins are reused in their original or similar applications, or by producing materials with added value, such as engineering plastics. If the properties of the resins are not compromised by the reclamation process, and if free enough of contaminants, generic resins can be sold to the manufacturers of

C&EN staff photo

Plastic lumber made from recycled resins is removed from ET/1 extruder at CPRR pilot plant

Chemical recycling of plastics is alternative to mechanical methods

In addition to mechanical methods of reusing plastics, such as molding or extruding, polyester resins also can be reclaimed through chemical means and used to produce new polymer compositions. Eastman Chemicals (a division of Eastman Kodak) and Freeman Chemical Corp. have led in developing the chemical recycling of polyester resins. By one of three reaction paths, polyethylene terephthalate (PET) can be used to produce polyols (for polyurethane foams) and unsaturated resins, or it can be broken down into its original starting components and repolymerized. Eastman Chemicals, through the Plastic Bottle Institute of the Society of the Plastics Industry, has provided detailed discussions of these reactions.

PET consists of repeating ethylene glycol and terephthalic acid (TPA) units joined together by ester linkages. Aromatic polyols, hydroxyl-terminated short-chain molecules consisting of TPA and glycol units, can be produced from PET in a one-step glycolysis reaction. The idea behind the reaction is very simple: High-molecular-weight PET is broken down into short-chain pieces through a catalytic reaction of PET and diethylene glycol. By heating a mixture of PET and diethylene glycol in the presence of a manganese catalyst, the polymer chain is cut into short fragments, and the ethylene glycol portions undergo exchange with the free diethylene glycol. This reaction is allowed to proceed until an equilibrium between the two glycols is reached and the PET has been reduced to short-chain polyols.

The aromatic polyols resulting from the reaction can be mixed with commercial polyols, blowing agents, surfactants, catalysts, and polymeric isocyanates to produce a rigid polyurethane foam. When compared with control foams produced from commercially available polyester polyols, the foams produced from reclaimed materials were found to have essentially the same properties.

Freeman Chemical uses about 25 million lb of postconsumer PET bottles and film scrap to make polyols for the production of rigid foams. The company estimates that more than 50% of the laminate foam insulation used for construction is made from recycled material.

PET resins also can be reused to produce new unsaturated polyester resins. This takes a two-step reaction. The first reaction is similar to that used to make the polyols but, instead of ethylene glycol, propylene glycol is used in the glycol exchange. The end products of this reaction include bis(hydroxyethyl)-terephthalate and bis(hydroxypropyl)terephthalate diesters, mixed ethylene glycol and propylene glycol terephthalate diesters, and free ethylene glycol and

plastic products as a replacement for virgin material. But Food & Drug Administration restrictions prohibit use of recycled resins in food applications, making one major plastics market inaccessible to recycled resins.

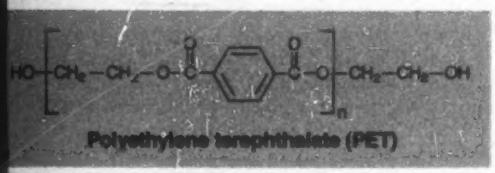
Mixed, or commingled, plastics must be dealt with differently to find end uses. Several technologies exist for mixed plastics, such as the ET/1 extrusion process from Advanced Recycling Technology of Belgium and a compression-molding process from Recycloplast of West Germany. At CPRR, another pilot plant with an ET/1 extruder has been installed to make plastic lumber out of mixed plastics. Lower-melting plastics in the mixture act as a matrix that carries other plastics, and even up to 40% contaminants, such as paper, metal, glass, and dirt, into the mold. The resulting product can be treated and used like wood in nonconstruction applications such as decks, picnic tables, and park benches. Reclaimed HDPE resins are also used to make flower pots, pipe, bottle base cups, pails, and drums.

A few companies make mixed plastic items commercially. About six years ago, Eaglebrook Plastics of Chicago started recycling HDPE plant scrap, developing its own technology for cleaning and reclaiming the resin to be sold back to manufacturers. Eaglebrook since has extended its technology to deal with postconsumer waste and now buys bales of bottles from community collection centers. An offshoot company, Eaglebrook Profiles, was recently opened to make plastic lumber profiles using a proprietary, continuous-extrusion process developed in-house.

Similarly, Polymer Products, a division of Plastic Recycling Inc. of Iowa, is a young company that has started buying industrial scrap and postconsumer plastics, generally commingled, to make car stops, speed bumps, traffic bollards, and plastic lumber. Floyd Hammer, chairman of Plastics Recycling Inc., says that when he started the company he had in mind to manufacture value-added products with their own end-use markets, rather than deal in the more volatile commodity resins. He noted that two years ago there wasn't a market for mixed plastics products, but that the company has been building its market slowly, but successfully, as one of the few small companies making these types of products.

In contrast, PET end-use markets have been developing for at least 10 years. When the PET bottle was introduced in 1978 and was collected in states with deposit laws, the industry for recycling them and reusing them began to develop. PET resins can be reused to make polyols for insulation and unsaturated resins for bathtubs, shower stalls, boat hulls, and auto panels. Reclaimed PET is also used for strapping, paint brushes, geotextiles, fibers for fiberfill and carpets, and other textile applications.

Wellman Inc. of Clark, N.J., the largest consumer of reclaimed PET, recycles PET beverage bottles and scrap to manufacture fibers, fiberfill, geotextiles, and other products. Dennis Sabourin, vice president of Wellman, indicates that the company used about two thirds of the PET bottles collected in the U.S., or about 100 million lb, in 1988. About 150 million lb of PET bottles were collected nationwide and recycled in 1988, or about 20% of those manufactured. This is a substantial increase over the 8 million lb collected in 1979 at a time when the return of plastic bottles was just begin-



Polyethylene terephthalate (PET)

propylene glycol. Since all of the products are hydroxyl-terminated, reacting them with a dibasic acid like maleic anhydride produces new unsaturated polyester condensates.

This synthetic method has been successfully tested on PET from beverage bottles (a 2-L bottle, for instance, consists of about 50 to 60 g of PET). Producing unsaturated resins from reclaimed PET takes about half the time as other methods and produces materials of equal molecular weight, acid value, and viscosity. Glass fiber-reinforced laminates and unreinforced castings prepared from the reclaimed PET material test favorably with other materials.

Although Eastman Chemicals does not currently use the unsaturated resin synthesis from reclaimed PET in its production, it does frequently use a methanolysis reaction, which breaks down PET into its original starting materials, to reprocess large amounts (tens of millions of pounds) of Kodak film scrap. As David Cornell, manager of technology and manufacturing in Eastman Chemicals' polyester recycling business unit, says, "It makes good sense for us at Eastman Kodak to recycle our scrap as it helps treat the solid waste problem and saves on our disposal cost."

The methanolysis begins with reasonably clean PET scrap to which a catalyst and methanol are added. This mixture is heated under pressure to force the PET to depolymerize. The end products are ethylene glycol and dimethyl terephthalate (DMT). Pure DMT and ethylene glycol are obtained through recrystallization and distillation, respectively. These pure materials can be used as feedstocks for the synthesis of new polyesters.

A few special considerations must be dealt with when reusing PET from consumer sources in chemical recycling. For example, the PET must be clean and free of contaminating materials. Using plant scrap assures the manufacturers of both the identity of the resin and its purity. Using mixed colored resins may pose a problem, although when they are used in products that are not visible to the consumer, such as foam insulation, color is not a factor.

Whether an economic advantage is realized when using reclaimed materials depends on several factors, ranging from the relative costs of obtaining and reprocessing the materials to the cost of virgin materials or feedstocks. In addition, the supply of materials and the scale of the reprocessing effort may play a significant role.

ning. CPRR estimates a potential market now for at least 500 million lb of reclaimed PET, increasing to more than 900 million lb in 1993. Similarly, 55 million lb of HDPE containers were recycled in 1988 and the potential market is estimated at 440 million lb, growing to 660 million lb in 1993. By most estimates the market for plastics reuse is growing.

According to an analysis of markets and economics of recycling by R. M. Kossoff and Associates of New York City, although the market for plastic resins can fluctuate widely, economic incentives are present in all aspects of the recycling chain. The firm sees the business as highly segmented, with opportunities at a variety of levels. These include collection, reclamation, selling of reclaimed resins, end-use products, and equipment manufacture. But as Richard M. Kossoff, director of the study, says, "In the long run, the markets will have to lead."

Increasing costs of virgin resins and viable end-use markets are currently making the recycling business attractive, and more and more companies, both large and small, are entering the business. The 1988 Plastic Bottle Recycling Directory and Reference Guide published by the Plastic Bottle Institute of SPI currently lists 67 companies that buy bulk bottles for recycling, 47 companies that sell reprocessed plastics, 50 companies that purchase reprocessed plastic, and 54 companies that manufacture equipment for recyclers.

Most people in the plastics recycling business will tell you they can always use more plastic than is currently available, but that the bottleneck is in getting the materials collected from consumers. Sabourin indicates that Wellman could use more than twice the amount currently available and as much as three and a half times that in the next two years. That more than 200 million lb of plastic containers were recycled with no organized recycling program, other than deposit laws in nine states, suggests that the level of plastics recycling and the requisite end-use markets will probably rise with increased collection efforts.

Having produced a working reclamation plant, CPRR is shifting its R&D emphasis to the areas of collecting and sorting plastics. The center is in the process of publishing another manual to help communities and industry establish the infrastructure for collecting and sorting plastics as a part of a comprehensive recycling program. In following the progress and analyzing the results of several community pilot programs, the center has found that the success of these programs depends on many factors. The most important factor is the careful design and planning of a program to fit a given community.

Even though including plastics in recycling programs is a new concept, participation rates can be as high as 70 to 90%. "If you want to get serious about collecting, you make it very simple for the consumer to participate," says Pearson. This usually means curbside pickup programs for trash and recyclable materials in suburban communities. In comparison, drop-off programs only have a 10 to 30% participation rate. Although mandatory recycling laws do help to directly communicate the need for recycling and enforce it, Pearson feels that with sufficient education about the solid waste problem and the value of recycling, most people are very willing to participate. And the value of education is not to be underestimated, because the

most difficult initial obstacles to overcome are the previous misconceptions people hold about plastics not being recyclable.

The extent to which a community gets involved in recycling depends on the economics of collection, transportation, handling, reprocessing, the revenues from sales of recycled materials, and the offset of landfill or incineration fees. The large number of variables makes the overall economics of recycling programs complicated. Based on current costs and market prices, the CPRR economic model predicts that an average suburban community with landfill charges of $45 per ton or more cannot afford not to recycle. Although this should encourage some communities to become involved in recycling, this does not mean that local governments must become entrepreneurs in the plastics end-use market. However, government subsidies to start programs and stimulate market growth might be necessary.

CPRR suggests that communities work toward developing regional Material Recovery Facilities (MRF) to handle all the recyclable materials collected. Several MRF facilities exist across the U.S., and the number being looked at is growing rapidly. These larger facilities, serving several communities, can handle sorting and densification (baling or shredding) in addition to sale and transport of recyclables to reprocessors.

Promoting recycling and collecting plastic containers has led to the development of other organizations. One of these is NAPCOR, the National Association for Plastic Container Recovery, a nonprofit association of 12 major PET resin and container manufacturers. "We work with communities in recycling efforts to either encourage including PET in existing programs or to have it included in programs under development," says Luke B. Schmidt, president of NAPCOR. NAPCOR has a goal of achieving a 50% recycling rate for PET bottles by 1992.

Geotextile fabric for sanitary landfill liners is made by Wellman Inc. from recycled green PET bottles

NAPCOR works on a project-by-project basis to encourage collection, Schmidt says. These projects are usually in demonstration programs. Currently, they are working in at least seven states giving financial support, technical assistance, and public education and promotion programs. In addition, the member companies of NAPCOR have pledged to use a voluntary coding system developed by SPI to identify resins. The code consists of a number and letter symbol that can be imprinted on containers in the molding process and should help in the sorting of resins.

The Plastic Bottle Institute of SPI and the Council on Plastics & Packaging in the Environment (COPPE) work to educate and provide information on plastics recycling and waste issues. The Plastic Bottle Institute, with 23 industrial members, publishes newsletters in addition to its extensive plastics recycling directory. Along with other organizations, it hopes to inform the public about the recyclability of plastics and the existence of viable end-use markets. COPPE works to communicate information to industry, the public, and government about plastics recycling and waste management.

"We want to educate the public as to what can and should be done so that decisions can be made on an informed and not an emotional basis," says Connie Pitt, communications coordinator for COPPE. Although not a lobbying organization, it does interact on matters of public policy as an information source and in a peer review capacity. There are 42 companies in COPPE that cover a broad base in the plastics industry. Noel H. Malone, manager of marketing in Eastman Chemicals' polyester recycling division, says that the large number of groups spanning the plastics industry is beneficial. "The industry is deep and wide, and specific groups can focus in on specific problems," he says.

New Jersey Division of Solid Waste Management deputy director Sheil is encouraged that the plastics industry appears to be joining together and moving forward on recycling. "Unlike other industries [glass and paper], the plastics industry is a very diverse group, ... especially by the time you get to the end product," she says. "If the states hadn't put the pressure on, it wouldn't have happened." Although the industry has come a long way toward recycling plastics, comments Sheil, recycling plastics hasn't yet become real on a large scale, and it will remain to be seen what happens in the next few years.

In addition to getting involved in recycling through organizations such as PRF, NAPCOR, and COPPE, the plastics industry is expanding its own internal efforts. Many of the major resin manufacturers, such as Du Pont, Dow Chemical, Mobil Chemical, and Eastman Chemicals, have taken positions on and responsibility for solid waste issues and established corporate divisions to focus on plastics recycling and/or solid waste management. These divisions look into the governmental, environmental, and business aspects.

Of course, companies see the support and promotion of plastics recycling as vital to their positions in the marketplace and the growth of their companies. As happened with the aluminum can, the promotion

Speed bump is one of a number of end use products made by Polymer Products from commingled plastics

of a product as recyclable lets the public perceive it in a positive light and helps to maintain a market. And joint ventures, acquisitions, and the building of recycling businesses offer the plastics industry new markets and promotional opportunities.

Mobil Chemical is a producer of polyethylene and polystyrene resins and a major manufacturer of polystyrene products. In addition to recycling all in-house scrap, the company purchases 100 million lb of polyethylene film scrap to use in the production of institutional trash bags. Robert J. Barrett, general manager of Mobil's Solid Waste Management Solutions unit, expects that business opportunities will continue to arise from the solutions to solid waste problems. An example is Mobil's $4 million joint venture company, Plastics Again, with Genpak of Glens Falls, N.Y.

Genpak, a plastic products manufacturer, and Mobil are in the process of opening and operating one of the first plants to recycle polystyrene foam items such as food containers, cups, and cutlery. The materials are being collected from Massachusetts schools and institutions by New England CRInc, a major reclamation firm and recycled materials end-use manufacturer. The plant has a capacity to recycle 3 million lb per year of polystyrene resin, which will be reused by the companies or sold to producers of insulation, fence posts, and flower pots. The new company is expecting a profit by 1992.

Similarly, Dow has entered into a joint venture agreement with Domtar of Canada to operate what the companies hope will be by 1990 a self-sustaining PET and HDPE recycling business. The North American company is expected to take postconsumer plastics and, using a proprietary Dow process, convert them into resins for use in Domtar's manufacturing or to be sold by Dow.

Other industry efforts to "close the loop" of product manufacture, recycling, and resin reuse include Procter & Gamble's marketing of a plastic household product container made from recycled PET. Johnson Controls, a major manufacturer of PET beverage bottles and containers, is also involved in promoting recycling efforts. Internally, the company recycles in-house scrap and is working on proprietary R&D efforts in recycling. As a container manufacturer, Johnson Controls is also taking an interest in the design of packaging to make it more recyclable. A company spokesman indicates that approaches are being worked on to begin marketing nonfood containers from recycled materials. Manufacturers looking to use recycled resins are concerned with getting consistent quantities and quality of the materials to make these efforts economically feasible.

Although plastics have been targeted in the battle on solid waste, and both government and industry have responded, plastics are only one part of the growing solid waste problem. The importance of investigating alternatives in waste disposal is becoming obvious to all involved. And new organizations, such as the Council on Solid Waste Solutions of the SPI, are growing out of the plastics and other industries. Unlike PRF, which emphasizes plastics recycling, the Council looks into all aspects of the solid waste problem, focusing on reaching local, state, and federal governments to influence legislation and on evaluating waste treatment technologies.

Alternative solid waste treatment methods are being explored and plastics recycling will probably continue to be among them, because it doesn't seem likely that our society will entirely give up their plastic products. Morrow makes the important point that plastics should be integrated slowly into the recycling scheme, starting with beverage bottles and moving on to other types of packaging, to provide time for the collection, reclamation, and end-use infrastructure to grow. Forcing too much, too soon, into the existing structure could do more harm than good in terms of a collapse of the effort and backlash from the apparent failure to recycle plastics. The outlook on biodegradable plastics, as generally expressed by the plastics industry, is that they may only find limited applications in agriculture or in dealing with litter.

EPA's Office of Solid Waste has proposed that an integrated system of waste reduction, recycling, incineration, and landfilling be established. This view seems to be supported by most industries and many legislative and environmental groups, but with different emphasis on the different components. EPA has also set a goal for recycling 25% of solid waste nationwide.

Although the details and issues of solid waste management are both complex and controversial, it appears that after reducing the amount of waste through recycling and burning that which can be safely incinerated in waste-to-energy conversion facilities, the levels of materials left for landfills can be greatly reduced. Still left to be dealt with are the issues of safe and cost-effective incineration, air and ash toxicity levels and disposal, establishment of a nationwide recycling infrastructure, and development of efficient and environmentally safe landfilling methods. □

ChemTek, like other venture capital operations, will look for a fairly aggressive return on its investments, Harvey says. The partnership will need a fairly high return—between 40 and 60%—to justify the high level of risk it will be undertaking in the certain knowledge that "not all our ventures will succeed." That is why, Harvey says, the partnership will seek minority investments in a portfolio of startup operations. "We know that some investments might not be productive and we may lose some or all of our investment."

ChemTek will be looking at specialty chemical ventures referred to it by other venture capitalists or referred via Battelle, Harvey says. "We'll also go to American Chemical Society meetings and visit areas of the country where there are large pockets of chemistry expertise," he adds.

Most of all, Harvey says, "we're looking for entrepreneurs with experience who will devote their full time to the venture." Although the technology is important, he says that the quality of a venture's management does make a difference in its success or failure. "Give me a grade 'B' technology and grade 'A' management anytime" over a spectacular new technology with unproven managers in charge, he adds.

Huthwaite says that the partners will be looking for specialty chemical ventures using a broad definition of specialty chemicals. As far as the partnership is concerned, anything that is not a commodity chemical business will be considered a specialty. Huthwaite says that the partners have 10 to 12 areas of particular interest. However, he is reluctant to discuss them for fear that in naming them he might inadvertently turn away someone with a venture the partnership might ultimately like.

Both Harvey and Huthwaite have practical business experience running startup business operations. Harvey, for instance, has headed up an electro-optics venture Du Pont had with Battelle. Huthwaite worked for a venture capital subsidiary of specialty chemical concern EchoLab in St. Paul, Minn.

Marc Reisch

Good growth forecast for fine chemicals

Fine chemicals have long been the stepchild of the chemical industry. Placed somewhere between commodity chemicals and the high-value-added specialty chemicals, these compounds, important though they are as intermediates to a number of industries, have gained little respect.

However, the situation may be changing as growth occurs in end-use markets for fine chemicals, according to a new study by Kline & Co., the Fairfield, N.J.-based market research group.

According to the study, the $15 billion fine chemicals business represents only about 8% of the $185 billion U.S. industrial chemicals market. But good growth potential and profitability are making this little-understood segment more attractive.

Fine chemicals are defined as high-value substances sold in low volumes. They go primarily to the pharmaceutical, agrochemical, dyes and pigments, and photographic industries. Kline cites examples of fine chemicals, including the analgesic acetaminophen, high-purity acids used in the production of semiconductors, and many of the intermediates used to make drugs and pesticides.

Fine chemicals, unlike performance chemicals which are usually formulated mixtures, are pure substances. They garner high prices because of their purity and complex processing.

The surge in interest in fine chemicals is being sparked by the rapid growth of generic drugs and agrochemicals in which fine chemicals are used as active ingredients and intermediates and by the level of activity in the merchant market. This is creating new challenges and opportunities for fine chemical suppliers.

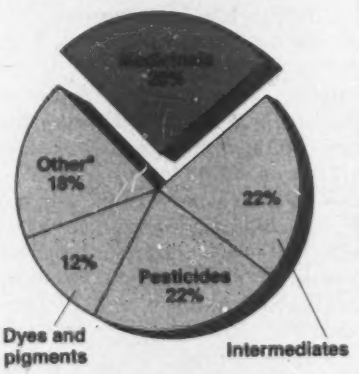
According to Kline, the growth in generics is occurring as pharmaceutical and pesticide companies are becoming more willing to purchase intermediates on the merchant market. This willingness to buy from merchant suppliers comes because of cost pressures and stringent government regulations, including waste treatment and disposal and compliance with Occupational Safety & Health Administration regulations.

The Kline study projects a real dollar growth rate of 3.4% per year over the next five years for fine chemicals. Segments showing better-than-average growth include bulk medicinals, aroma chemicals, essential oils, food-grade chemicals, electronic chemicals, and various types of intermediates. Kline expects growth in the merchant segment of the market to outpace the market as a whole.

The structure of the fine chemicals industry can be classed into three types of companies, according to Kline. Captive producers, such as Monsanto, BASF, and Ciba-Geigy, produce fine chemicals primarily for their own pharmaceuticals, dyes and pigments. pesticides, and photographic products. They also sell to a lesser extent on the merchant market. Independent suppliers, like ChemDesign of Fitchburg, Mass., and White Chemical of Newark, N.J., have fine chemicals as their chief business and sell primarily on the merchant market. A third group includes integrated business units of major chemical companies such as PPG Industries and Occidental Chemical.

William Storck

Medicinals are largest share of fine chemicals market



Total 1987 consumption = $15 billion

a Includes aroma, photographic, and food chemicals.
Source: Kline & Co.

Past Decade Shows No Gain In U.S. Science Literacy

New studies that also allow comparison of science literacy in U.S. and U.K. show "dismally" low levels in both countries

James Krieger, C&EN Washington

There has been no significant change in the level of science literacy among American adults in the 1980s, according to evidence from a recent national survey of public knowledge in the U.S. about science and technology.

Moreover, another new survey of science literacy carried out in the U.K. broadens the scope: "In two of the world's oldest and most prominent democracies, at least nine out of 10 citizens lack the scientific literacy to understand and participate in the formulation of public policy on a very important segment of their national political agendas," says political science professor Jon D. Miller, director of the Public Opinion Laboratory at Northern Illinois University, which undertook the U.S. survey.

More specifically, results of the U.S. study indicate that only about 6% of American adults are scientifically literate, that no progress has been made in this regard over the past decade, and that a meaningful solution involves longer-term changes in the educational system. "The British results," Miller says, "suggest that we are not alone in our problems, and I think that it is most likely a problem faced by virtually all industrialized nations."

To what extent that is the case may become better known in the near future. The U.S. and U.K. survey results were presented at a symposium on cross-national measurements of public understanding of science and technology, held during the annual meeting of the American Association for the Advancement of Science earlier this month in San Francisco. Presiding at the symposium, Jean Gabolde, director for scientific and technical policy of the Commission of the European Communities, Brussels, noted that surveys of European countries are planned.

Gabolde stressed the need to be able to compare the European Community's 12 member countries, which are not in the same state of scientific development. Come 1990, he says, studies of the public perception of science and technology will exist for the U.S., U.K., Japan, Europe, and European countries. The European studies, he says, will use the same approach as that taken in the U.S. and the U.K.

Meanwhile, the U.S. survey and that in the U.K. are bringing refinements to the study of science literacy. The U.S. effort, for instance, builds on two previous surveys carried out by Miller and his colleagues at the Public Opinion Laboratory and forms a bridge to them.

Miller points out in relation to the concept of literacy in general that the level of skill or ability in reading and writing should be viewed as a continuum, ranging from virtually no skills to the most sophisticated writing ability. In contrast to a continuous distribution, however, literacy is a threshold measure.

And it is a relative measure, Miller notes. The level of skills needed for a person to be considered literate changes over time. Also any definition of literacy is inherently relative to the character of the society in which it is used—the same definition of functional literacy, for example, not being appropriate for

New survey of U.S. science literacy provides bridge with past measures . . .

	Trend measure with 1979 and 1985 variables[a]	New measure with 1988 variables[b]
Estimate of science literacy	5.6%	5.6%
Understanding of scientific process of thinking	12.1	12.1
Understanding of scientific terms and concepts	34.0	28.1
Understanding of the impact of science and technology	53.0	49.9

. . . and permits a comparison of science literacy in U.S. and U.K.

	U.S.	U.K.
Estimate of science literacy	5.6%	7.1%
Understanding of scientific process or thinking	12.1	10.4
Understanding of scientific terms and concepts	28.1	28.5
Understanding of the impact of science and technology	49.9	57.6

Note: Number of responses = 2041 (U.S.) and 2009 (U.K.). a Calculation using same variables employed in 1979 and 1985, but using 1988 data. b Calculation using new variables and 1988 data.

Quiz items form basis for Anglo-American comparative index of science knowledge

	Percent correct U.S.	U.K.
The center of the Earth is very hot	80.3%	86.3%
The oxygen we breath comes from plants	80.6	59.9
Radioactive milk can be made safe by boiling it	64.1	65.1
Lasers work by focusing sound waves	36.0	41.8
Sunlight can cause skin cancer	96.9	93.5
Hot air rises	97.0	96.7
Electrons are smaller than atoms	42.7	30.9
The continents are moving slowly about on the surface of the Earth	80.1	71.7
Antibiotics kill viruses as well as bacteria	25.5	25.6
The earliest humans lived at the same time as the dinosaurs	36.8	46.2
Which travels faster, light or sound?	76.1	74.7
Is all radioactivity man-made or does some occur naturally?	65.3	74.3

	Percent correct U.S.	U.K.
Does the Earth go round the sun, or does the sun go round the Earth?	72.5	62.8
How long does it take for the Earth to go round the sun?	44.9	34.1
Doctors tell a couple that their genetic make-up means that they've got a one in four chance of having a child with an inherited illness. Does this mean that:	71.1	82.1
• If they have only three children, one will have the illness?		
• If their first child has the illness, the next three will not?		
• Each of the couple's children has the same risk of suffering from the illness?		
• If their first three children are healthy, the fourth will have the illness?		

both advanced industrial societies and Third World agricultural societies. Further, the selection of a threshold level for the definition of literacy is not an exact science, but rather a judgment.

For science literacy, Miller and his associates have tried to develop measures that would indicate what a citizen needs to know to be reasonably effective and to function in society. Knowing Earth goes around the sun, he explains, isn't considered to be optimal about what one ought to know about the universe. Rather, it is an attempt to establish a floor to see how many people fall above and below that floor.

And science literacy is not unrelated to general literacy. The problems associated with basic literacy in U.S. society, Miller says, are serious and are relevant to concerns about a broader public understanding of science and technology. "For those millions of Americans who are not functionally literate," he says, "the world of science is as distant as Pluto."

Miller directed previous national surveys of U.S. science literacy in 1979 and again in 1985 (C&EN, June 23, 1986, page 37). They made him aware, he says, of a need for improved measures of science literacy. With National Science Foundation support, he was able to design and collect the most recent survey in the summer of 1988. A similar study was being conducted at the same time in the U.K. by John Durant, deputy director of the department of external studies at the University of Oxford, and his colleague Geoffrey Evans.

Durant and Evans collaborated with Miller to establish a domain of overlap between the two questionnaires being used, so that a comparison could be made of public understanding of science in Britain and the U.S. Durant says that this collaboration is the first he is aware of in which two independent surveys have been expressly designed for this purpose. Durant presented the first preliminary results of the U.K. survey and of work on the data sets involving the two.

The Northern Illinois surveys have been based on what Miller thinks of as the three dimensions of science literacy: an understanding of the process or methods of science for testing models of reality, a basic vocabulary of scientific and technical terms and concepts, and an understanding of the impact of science and technology on society. The 1988 survey continued that framework, but revisions aimed at improving it involved changes in the items used to measure two of the three dimensions.

An open-ended question about the meaning of scientific study forms the core of the measure of public understanding of the process of science. As a check against this open-ended question, all the studies have included a set of items about astrology, one of which asks whether astrology is very scientific, moderately scientific, or not at all scientific. To be classified as having a minimally acceptable level of understanding of the process of science, a respondent had to be able to provide a satisfactory open-ended explanation of what it means to study something scientifically and to recognize astrology as not at all scientific. By this measure, 12% of American adults displayed a minimally acceptable level of understanding, compared with 9% in 1979 and in 1985.

On the science literacy dimension of vocabulary, or scientific constructs, Miller argues that if an individual cannot comprehend basic terms like atom, molecule, cell, gene, gravity, or radiation, then it would be nearly impossible for that person to follow much of the public discussion of scientific results or public policy issues pertaining to science and technology.

To measure such comprehension, the 1979 and 1985 surveys included a series of two-part knowledge items that first asked each respondent to rate his or her own comprehension of a term. If the respondent reported a clear understanding or a general sense about a term, he or she was asked to explain what the word or phrase meant in an open-ended response. If the respondent indicated little understanding, he or she

wasn't asked for further explanation. The approach made the data collection more acceptable to adult respondents.

The scientific knowledge measure in the 1979 and 1985 studies was based on self-reported items for radiation, DNA, and GNP [gross national product]. These same items were repeated in 1988 to allow for a comparison. (34% of American adults in both 1988 and 1985 reported at least one clear understanding and one general sense on these three items, thus meeting a minimal criterion for scientific vocabulary.)

The 1988 U.S. and U.K. studies included an expanded number of scientific and technical knowledge items, some in a true-false quiz format and others posed as freestanding questions. Each study included 15 to 20 scientific and technical knowledge items, 10 of them identical in the two studies. In the U.S. study, respondents could score from zero to 10. For constructing an index of scientific literacy, those with a score of seven or more on this measure were classified as having an adequate level of understanding. In the 1988 study, about 28% of American adults met this criterion.

The third dimension of science literacy concerns an understanding of the impact of science and technology on society broadly and on the daily lives of individuals as consumers, parents, and citizens. As implemented in the three studies, this dimension went beyond such scientific understandings as the size of an electron or the time location of humans and dinosaurs. The idea is that for what might be thought of more broadly as technological literacy, some knowledge about computers or antibiotics or radioactivity might aid a person in coping with some of the technologies or public policy issues that he or she may confront currently.

The 1988 study involved construction of a six-item index to measure this technological literacy dimension. For example, respondents received one point each for providing a "false" response to several statements, such as antibiotics kill viruses as well as bacteria. One point each was also given on several other items—for example, indicating that all the children of a couple with a one-in-four chance of transmitting a genetic condition would have the same probability of having that condition. Respondents with a score of three or more out of six were classified as having an adequate understanding of the impact of science, or an adequate level of technological literacy. Some 50% of adult Americans met this criterion in 1988.

Miller admits to not being satisfied with the measurement of this dimension. But he says that given the items collected in previous studies and in 1988, it is the best estimate available, and the 1988 measure is an improvement over the previous measures.

Combining the three separate indexes leads to the finding that approximately 6% of American adults can be classified as scientifically literate in 1988. This compares with levels of 7% in 1979 and 5% in 1985.

As a check on the changes in two of the dimensions, the research group calculated the 1988 estimate of scientific literacy twice. One calculation, Miller explains, used the same variables employed in 1979 and 1985, but used 1988 data. The other calculation used the new variables and the 1988 data. In both cases, the overall scientific literacy estimate came out to be 5.6%—indicating, Miller says, that the new measures are an appropriate bridge to previous measures.

The new study also explored more broadly the distribution of scientific literacy. Five variables were studied. Age was investigated, with respondents separated into three groups: 18 to 29, 30 to 50, and 51 and over. In terms of education, respondents were also separated into three groups: less than high school graduation, high school graduates, and baccalaureates. Gender was explored. Separation was also made according to respondents having had no college-level science courses (biology, chemistry, or physics) versus those having had some courses. And included was a measure reflecting whether the respondent's employer is engaged in scientific or engineering work.

Miller says that if a single variable had to be chosen to predict science literacy, that single one is having taken one or more college-level science courses, even for people who did not finish college or who were two-year college students. Obtaining a baccalaureate adds marginally to the likelihood of being scientifically literate, he says, but it is clear that it is the science course experience rather than the general degree experience that makes a difference. By inference, he adds, this result suggests that the high school science experience has little impact on subsequent scientific literacy.

All of the measures used to construct the estimate of scientific literacy for the U.S. were collected in the U.K. at about the same time. Oxford's Durant explains that the U.K. quiz consisted of more than 20 straightforwardly factual questions on a wide range of sciences, including mathematics, physics, geology, chemistry, and biology. Together, these items constitute what the research group has termed the Oxford Scientific Knowledge Scale. It was used along with a smaller battery of items on the processes and norms of scientific inquiry to provide the analysis of British public understanding of science. From the Oxford Scientific Knowledge Scale, 14 items overlapped with the U.S. study to form the basis for a comparison.

The results, Durant says, don't justify much cause for complacency in either country. He notes, for example, that on an extremely elementary factual science quiz, "the American public performed only slightly less dismally than the British." He notes that on one item, under half of Americans and under a third of Britons know that an electron is smaller than an atom. And another item shows that about the same proportions in each country know that Earth goes round the sun once a year.

"Now, for most of the public not to have caught up with Sir J. J. Thompson, Robert Millikan, Niels Bohr, and all the rest may perhaps be excused on the grounds of the relatively esoteric nature of atomic physics," Durant says. "But what reason shall we give for the fact that most of the public has not yet caught up with Nicolaus Copernicus and Galileo Galilei?" □